THE TIMING OF DISTRACTION OF AN OSTEOOTOMY

S. H. WHITE, J. KENWRIGHT

From Nuffield Orthopaedic Centre, Oxford

New methods of limb lengthening are being adopted in the hope of overcoming the poor osteogenic responses characteristic of distraction. Delay between the osteotomy and starting distraction is said to be important but there is little experimental evidence.

We have compared immediate with delayed distraction in the rabbit tibia and shown that delay is an important factor in promoting osteogenesis. It seems that its effects are partly mediated by an improvement in the extra-osseous blood supply.

Leg lengthening is a clinical problem; poor bone healing after it may result in atrophic non-union or a high risk of refracture. Many surgeons are trying new methods, using various combinations of techniques such as a medullary preserving osteotomy (Ilizarov and Pereslytskikh 1977; Monticelli and Spinelli 1983), delayed distraction (De Bastiani et al 1987), biplanar fixation with fine Kirschner wires (Ilizarov and Berko 1980), and changing the rate and rhythm of distraction (De Bastiani et al 1987). However, very little is known of the relative importance of these factors on bone healing; most studies have varied more than one of them. Kojimoto et al (1988) have recently challenged the stress which has been placed upon preservation of the medulla in an experiment which demonstrated excellent bone healing following medullary destruction so long as the periosteum had been carefully preserved.

We have investigated the significance of the factor of delay, which to our knowledge has not been studied as an isolated variable. Our aim was to investigate the biomechanical and biological responses to immediate and delayed distraction in an experimental model.

MATERIALS AND METHODS

Diaphyseal tibial osteotomies and leg lengthenings were performed in 24 adult male New Zealand rabbits which were randomly divided into two groups. In one group distraction started immediately and in the other, after an interval of seven days. The operative procedure was identical in both groups and involved the application to the tibia of a dual frame, uniplanar external fixator using four 1.6 mm Kirschner wires, two proximally and two distally (Fig. 1). A mid-diaphyseal osteotomy of the tibia was performed using a Gigli saw, after which the
periosteum was repaired. Distraction by 0.5 mm per day for 20 days produced a 10% lengthening of the adult tibia. Strain gauges bonded on to the fixator columns were used to measure the tensile load during distraction.

At 42 days, contact microradiographs were made. The volume of mineralised callus was calculated using magnified anteroposterior and lateral contact radiographs overlaid with a graticule (Fig. 2). For each transverse section the product of the width of mineralised callus on the anteroposterior film and its depth on the lateral film was proportional to the cross-sectional area.

The sum of the surface area measurements for each layer was proportional to the volume. Comparisons of the volume of mineralised callus were then made from one specimen to another.

Micro-angiography used a modification of Rhinelander's technique (Rhinelander, Stewart and Wilson 1979) in which a 50% solution of barium sulphate and 2% solution of Berlin blue were injected into the aorta at a pressure of 120 mmHg after washing out the blood with a 1% solution of sodium nitrate (Garcés 1987). Following fixation in 10% formaldehyde and decalcification in 10% nitric acid the specimens were divided in the coronal plane. The posterior half was embedded in methylmethacrylate and contact micro-angiographs were made of alternate 200 and 1 000 μm sections. The anterior half was stained with haemotoxylin and eosin and with trichrome blue; sections were sampled at 400 μm intervals.

RESULTS

The volumes of mineralised callus as calculated from contact microradiographs are shown in Figure 3, and were 2.6 times as great after delayed than after immediate distraction (p < 0.01). Immediate distraction resulted in small cones of callus. The osteogenic response was more variable following delayed distraction; examples are illustrated in Figure 4.

In both groups of rabbits the cut bone ends were still clearly visible; typically the proximal pole made a greater contribution to healing than the distal pole. At six weeks a radiolucent line could be seen crossing the gap towards its distal end in both groups.
Histology confirmed the radiological findings of increased callus following delayed distraction (Fig. 5). After immediate distraction callus formed predominantly from the proximal end but distally, there was a tendency to fibrous tissue interposition crossing the osteotomy gap (Fig. 5a). This contrasted with delayed distraction, where the lengthened segment contained two large masses of woven bone separated by a narrow zone of cartilage and fibrous tissue; cartilaginous elements predominated in this zone (Fig. 5b). Higher magnification showed this zone to contain longitudinally orientated columns of cartilage cells being replaced both proximally and distally by new bone. There was also longitudinal orientation of the fibrous tissue after immediate distraction (Fig. 6).

Micro-angiograms of these same specimens, cut within 2 mm of the histological level, showed that the soft callus contained vessels with a greater proportion arising proximally. After immediate distraction (Fig. 7a) there was a lower density of blood vessels throughout the gap and particularly in the fibrous zone. After delayed distraction there was a greater overall density of vessels. The vessels in both groups were derived in part from the

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**Fig. 5a**
Low power views of sections at six weeks after immediate distraction (5a) and delayed distraction (5b).

**Fig. 5b**

**Fig. 6a**
Higher magnification of boxed areas in Figure 5. Figure 6a – Interface between proximal mineralised callus and fibrous tissue after immediate distraction. Figure 6b – Growth zone between proximal callus (top right) and distal callus (bottom left) after delayed distraction. There is longitudinal orientation of the cartilage cell columns.
extra-osseous tissues and in part from the medullary vessels, but in the delayed group the extra-osseous, periosteal contribution was much more proliferative than in the immediate distraction group. In the delayed group (Fig. 7b), the narrow, avascular cartilaginous gap was served on each side by a rich capillary network where osteogenesis was taking place.

The tensile forces across the gap are shown after immediate distraction in an example in which the gap contained much fibrous tissue at six weeks (Fig. 8a) and after delayed distraction in a tibia which showed the early stages of bony bridging (Fig. 8b). When distraction started immediately, the maximal daily increase of tensile load was 25 N, but a strikingly different pattern was seen after delay. Seven days after osteotomy at the start of delayed distraction, a force close to 100 N was required to distract by just 0.5 mm. Later in the course of distraction, at day 12, the load fell; this may have indicated interruption of the callus.

**DISCUSSION**

Delay in distraction was frequently used by pioneers of bone lengthening (Barr and Ober 1933; Bosworth 1938). They performed massive soft-tissue releases and waited for one week to allow the soft tissues to heal. Abbott and Saunders (1939) described “excellent callus production” when they waited 10 days before distracting a patient’s osteotomy. Kawamura et al (1968) were the first to question the importance of delay – “if the operation is performed with minimal dissection of the soft tissues such delay does not seem necessary”. The more recent techniques of Anderson (1967) and of Wagner (1978)
involve immediate distraction without soft tissue release. De Bastiani et al (1987) advocated waiting 10 days before lengthening and calls the process callotasis, describing more proliferative bone formation associated with such delay in clinical lengthening. There is little experimental evidence to support these clinical observations.

Our study has shown that delay in distraction of an osteotomy in a small mammalian model influenced the osteogenic response. Immediate distraction was followed by the histological appearance of more fibrous tissue between the bone ends. In contrast, a delay of seven days before distraction resulted in a larger volume of callus, and a smaller radiolucent gap, which contained proliferating cartilage between zones of intense osteogenesis. Furthermore, there was a rich capillary ingrowth on either side of this growth zone. Not only was more bone formed in the delayed group, but the gap was smaller, and chondrocytes predominated as opposed to fibrous tissue. In both groups the cartilage or fibrous tissue elements were orientated longitudinally, reflecting the longitudinal tension. The new vascularity in both groups was both extra-osseous and intra-osseous.

We showed marked differences between the two groups, but recognise the limitations in the type of measurement we used. We measured callus from radiographs, a method with known limitations, but within these limitations we found highly significant differences between the two groups.

In assessing vascularity by an injection method we used a carefully standardised protocol; but there are limitations due to pressure differences between one specimen and another. The method does not reflect blood flow, but our results did show marked differences in the density of vasculature. We chose to end the study at six weeks, before sound consolidation had occurred in either group, in order to study the early effect of delay on bone formation, before remodelling had occurred.

There are several possible explanations for the influence of delay on an experimental osteotomy. Mulholland and Pritchard (1959) in a study of 174 rib fractures showed that there is a critical distance between bone ends beyond which union will not occur. First, immediate separation of the freshly-cut bone ends may inhibit the proliferation of osteoblast precursor cells; delay might promote their accumulation.

Secondly, it might be that local repair of the damaged blood vessels occurs most effectively under stable conditions in the first week; this stage could be frustrated by immediate and repeated traction. Our tension studies showed that the extra-osseous circulation, once formed, could withstand a distraction force up to 100 N and still maintain vascularisation of the callus. The better vascularity seen in our delayed distraction group suggests that delay does permit the establishment of a resilient extra-osseous blood supply that can withstand tensile forces. More callus was seen at the proximal bone end in both groups; this may reflect the better blood supply of the proximal tibia, since the nutrient artery enters the rabbit tibia just proximal to the level of the osteotomy.

Our findings were for the particular conditions we defined. Other types of experimental and clinical response have been described for different conditions and variations; these might influence the response to delay in distraction. Recent clinical investigators have shown distinctly better osteogenic responses by varying several aspects of the distraction regime, such as the type of the osteotomy, the rate and rhythm of distraction, the level of osteotomy and the mechanical conditions of fixation.

We chose a rate and rhythm of 0.5 mm per day in one dose; it has been shown that smaller daily increments in four doses result in similar radiographic appearances. Ossification under these different conditions is however intra-membranous (Aronson and Harrison 1987).

The mechanical conditions of the frame and the stability of the osteotomy may also be important, as has been shown for the healing of fractures in both experimental and clinical studies (Sarmiento, Latta and Tarr 1984; Goodship and Kenwright 1985; Williams et al 1987). The conditions in our study provided relative instability at the osteotomy, especially to shear deformation. It is possible that a different response would follow a more rigid fixation.

The type of osteotomy may also influence the healing pattern. Clinical leg lengthening is now frequently performed by a cortical osteotomy, in an attempt to minimise periostial damage and maintain the intra-medullary blood supply (Ilizarov and Pereslytsskikh 1977; Monticelli and Spinelli 1983). It is possible that preservation of medullary blood supply is an important factor in the enhanced healing described by Ilizarov both clinically and experimentally. It is probable that the recovery of the blood supply during the first week contributes to the more prolific osteogenic response we saw after delayed osteotomy. The delay of seven days in our study applies to the rabbit model; it is possible that in patients a longer period might lead to an enhanced osteogenic response.

We have shown that immediate distraction tends to result in a small volume of callus with deficient vascularity and a tendency for fibrous tissue interposition. Delay before distraction results in a narrow zone of proliferating chondrocytes between the bone ends and intense osteogenesis with a rich vascularity. We have discussed various explanations for this difference, but have confirmed that delay in itself, before distraction is applied, leads to more prolific bone healing under the conditions defined in our study.

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REFERENCES


